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THE SURFACE TENSION OF MOLTEN METALS

PART II

A DETERMINATION OF THE CAPILLARY CONSTANT OF SILVER

BY

EARL E. LIBMAN

BULLETIN No. 187

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A DETERMINATION OF THE CAPILLARY CONSTANT OF SILVER

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THE SURFACE TENSION OF MOLTEN METALS, PART II A DETERMINATION OF THE CAPILLARY CONSTANT OF SILVER

I. Introduction

1. *Surface Tension.*—The mutual attractions of the particles of a liquid endow its surface with the properties of a stretched elastic membrane. The liquid thus acts as though its surface were subjected to a tangential tension. The magnitude of this stress, when the substance bounding the surface is the vapor of the liquid, is called its "surface tension." Under the influence of this force the liquid ascends or descends in a tube of small bore placed vertically with its lower end submerged. This action is most marked in the case of tubes of very fine bore, bores of hair size called capillaries (Latin "capilla" meaning hair). For this reason the phenomena arising from surface tension are grouped under the heading of "capillarity."

For a detailed account of the theory underlying capillarity the reader is referred to Bulletin No. 173 of the Engineering Experiment Station of the University of Illinois. There will be found a mathematical analysis which, beginning with the assumption that each particle of the liquid is attracted by every other particle, leads to formulas connecting the shape of the surface of a liquid with its surface tension. As there will be frequent occasion to refer to this bulletin, it will in the future be denoted simply by "Bulletin 173."

2. *Previous Work on Surface Tension of Molten Silver.*—In Bulletin 173 will be found several tables giving typical data from the work done on the surface tension of molten metals in general prior to that reported therein. Table 1 gives values taken from Table 1 in Bulletin 173 which indicate the crudeness of previous measurements upon silver.

A discussion of these results and the reasons for their disagreement will also be found in Bulletin 173. It is to be noted that no temperature is recorded with these data. Presumably the measurements were made in the vicinity of the melting point.

3. *Importance of Surface Tension Data for Metals.*—When a substance is molten the only forces acting upon it are gravity and the intermolecular attractions that manifest themselves in the phenomenon of surface tension. It follows that the behavior of the molten materials will be closely related to their surface tensions and that an extension of our knowledge of this property should lead to a greater insight into the peculiarities exhibited by molten metals.

TABLE 1

PREVIOUS DETERMINATIONS OF CAPILLARY CONSTANT OF SILVER

Date	Observer	Value of Capillary Constant a^2 for Silver cm.^{2}
1868	Quinke	0.1594
1899	Gradenwitz	0.145
1914	Smith	0.1852

$a^2 = 2T/g\rho$ in cm.^{2}
ρ = density
T = surface tension in dynes per cm.
g = acceleration due to gravity
When the value of the capillary constant a^2 is determined, the calculation of the surface tension T is possible when the value of ρ, the density, is known.

Surface tension is the governing factor in all processes of welding, soldering and joining. It has recently been shown* that those fluxes that are most effective in soldering are just those whose presence causes a lowering of the surface tensions of the metals that become molten in the soldering operation.

The mutual solubilities of the molten metals, and the behavior of such solutions upon cooling and before solidification, should likewise be so related to the surface tensions that a knowledge of the latter will allow a prediction of the former.

In casting operations where sharp outline is necessary the surface tension of the molten metal is the governing factor. Metals with high surface tension will not flow into sharp corners or crevices and if the latter be sufficiently fine an enormous pressure would be required to force the liquid into them.

It appears, therefore, that in the progress of metallurgy surface tension data are a growing necessity, and the fact that most of their applications are still in a formative state is due more to the lack of such data than to any doubt concerning their importance.

At present the greater part of the scientific world is investigating the structure of the atom and molecule. The property of the cohesion of fluids (and of solids as well) is one intimately connected with atomic and molecular structure and any knowledge gained concerning the phenomenon, surface tension, which is a direct result of those cohesive forces, is a step in the solution of this great problem.

4. *Acknowledgments.*—This investigation has been a part of the regular work of the Engineering Experiment Station of the University of Illinois, of which DEAN M. S. KETCHUM is the director, and of the Department of Physics, of which PROF. A. P. CARMAN is the head.

*A. W. Coffman, doctor's dissertation, Chemistry Department, University of Illinois. 1927.

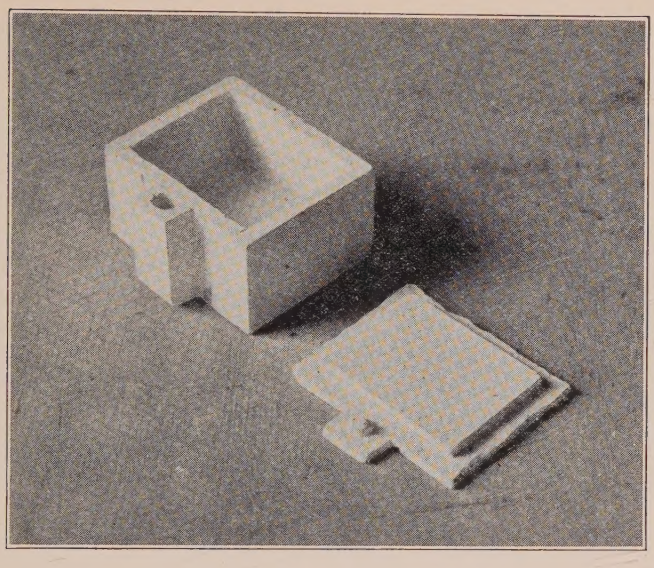

FIG. 1. SPECIAL CRUCIBLE

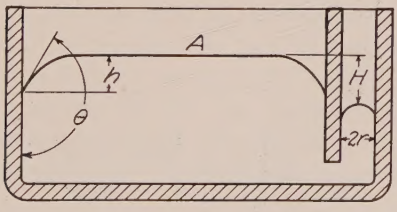

FIG. 2. PLANE AND CAPILLARY DEPRESSIONS OF MOLTEN METAL IN CRUCIBLE

The author wishes to acknowledge the coöperation of PROF. CHAS. T. KNIPP, of the Department of Physics, in the early stages of the work, and the assistance of MR. JOHN G. THEWS, Assistant in Physics, who worked with him throughout the course of the investigation.

II. METHOD USED IN THIS INVESTIGATION

5. *Experimental Method.*—The silver was placed in a crucible of special shape as shown in Fig. 1. This resided in a molybdenum resistor vacuum furnace. The temperature was raised to the desired points and X-ray photographs were taken through the entire furnace. These gave shadowgraphs of the metal in the crucible (Fig. 2).

From measurements of h and H the surface tension may be calculated. A typical X-ray photograph from the negative of which measurements were made is shown in Fig. 3.

The general aspect of the furnace may be obtained from Fig. 4. The method is that devised by the writer and described in detail in Bulletin 173.

6. *Theory of Method.*—For the mathematical theory of the method employed the reader must again be referred to Bulletin 173. On the basis of the general theory of capillarity and by a method of successive approximation the following fundamental formulas are there derived.

$$\text{A} \begin{cases} h^2 = a^2(1 - \sin\theta) \\ a^2 = \dfrac{Hr}{-\cos\theta} \text{ (approximate)} \end{cases}$$

$$\text{B} \begin{cases} m^2 = \dfrac{r^2}{\left(\dfrac{a^4}{H^2}\right)} - r^2\tan^2\theta \\ \alpha = \dfrac{a^2m^2}{H} \\ a^2 = \dfrac{rH}{-\cos\theta} + \dfrac{\left[r\alpha + \left\{\dfrac{2(\alpha^2 - m^2r^2)^{\frac{3}{2}}}{3m^2r}\right\} - \dfrac{2\alpha^3}{3m^2r}\right]}{-\cos\theta} \end{cases}$$

Here the meanings of r, h, H and θ are given in Fig. 2 and that of a^2 below Table 1.

From the values of h and H obtained experimentally, equations A give approximate values for a^2 and θ. Substituting these in equations B we get the correction term to our approximate a^2. This corrected value of a^2 could be reapplied to obtain a still better approximation, but experience shows a single application to be sufficient.

7. *Discussion of Errors.*—In Bulletin 173 there is given a detailed discussion of all the errors involved in the method here used. This analysis takes into account not only the errors of observation but also those involved in the one assumption made in applying the general theory of capillarity to the experimental method. This assumption is

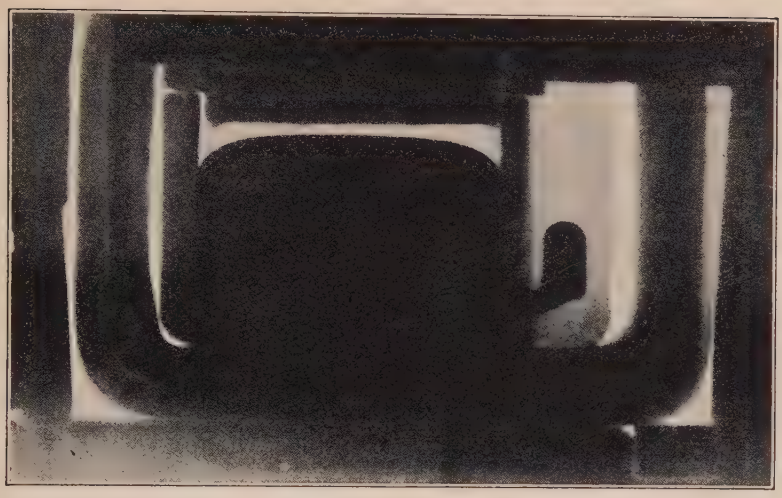

FIG. 3. REPRODUCTION OF TYPICAL X-RAY PHOTOGRAPH FROM THE NEGATIVE OF WHICH MEASUREMENTS WERE MADE

that the surface of the liquid in the reservoir is flat at the point A of Fig. 2. If this is not true then the surface at point A will be depressed by an amount D beneath the level it would otherwise occupy (Fig. 5), and the error thus caused must be considered.

Applying the analysis carried out in Bulletin 173 in precisely the same manner as detailed there on page 23, but inserting the data for silver instead of that for copper, there results for D the value 0.001 cm.

The neglect of this amount causes an error of equal magnitude in H and of 0.0007 cm. in h. These correspond to probable errors of 0.001 cm. in both H and h which, as reference to the tables will show, is larger than the probable errors of observation.

(The error of 0.001 cm. in H, and of 0.0007 cm. in h, correspond to percentage errors of less than 0.2 per cent.)

Still following the analysis of errors given in Bulletin 173, we next determine the effect of these errors and those of measurement upon the calculated value of the capillary constant a^2. Since the probable error of 0.001 cm. for h and H is larger than those of observation we will take this value for the probable error in each. For the probable error in the radius r of the capillary tube we take the largest value of the probable errors of measurement, namely, 0.0008 cm. With these values we get, by the method of Bulletin 173, page 28, for the maximum probable error in a^2, 0.0007 cm^2.

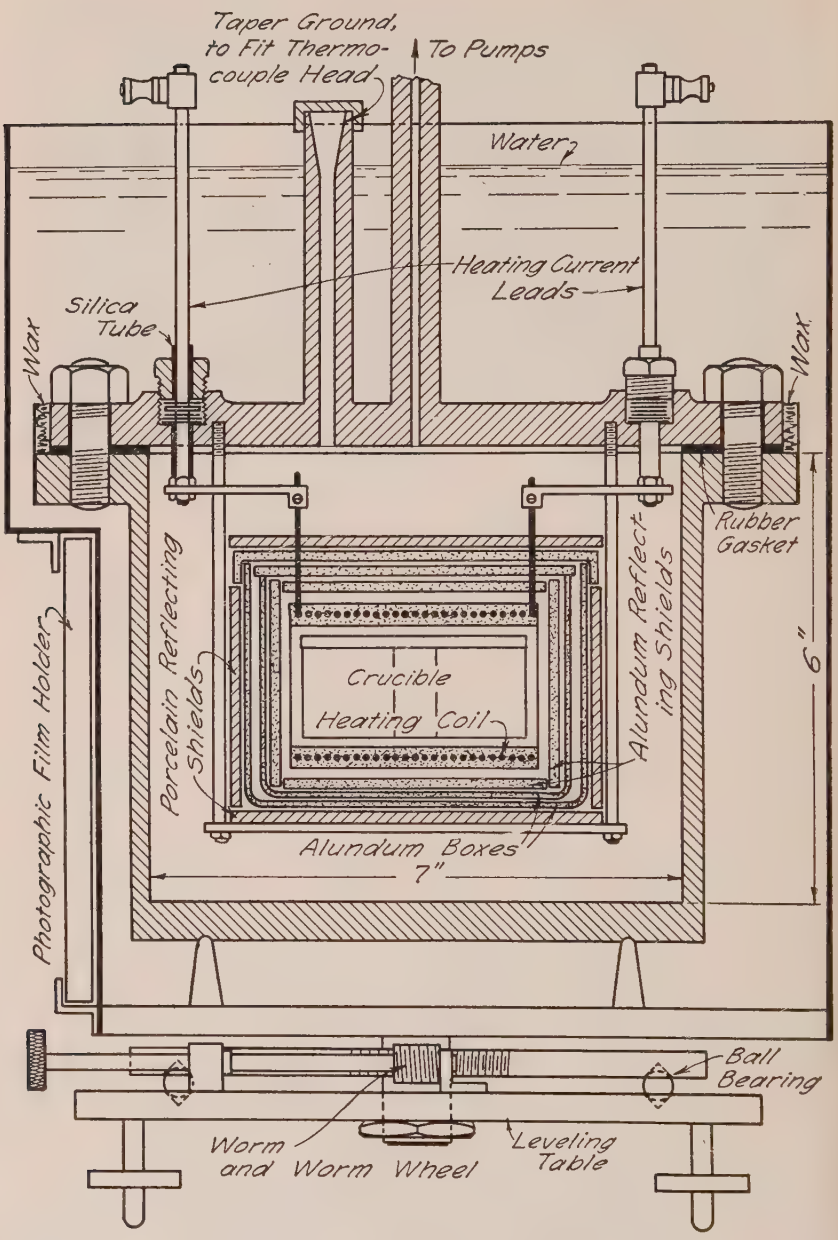

FIG. 4. SECTIONAL DETAILS OF VACUUM FURNACE

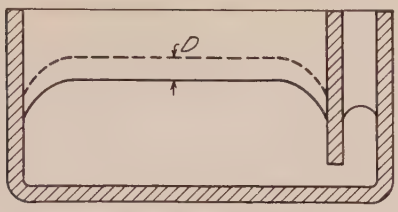

FIG. 5. DEPRESSION OF SURFACE OF MOLTEN METAL IN CRUCIBLE

III. MATERIAL USED IN THIS INVESTIGATION

8. *Analysis of Silver Used.*—The silver used in this investigation was obtained from the United States Mint and was marked "200 fine." After use it was subjected to chemical analysis by Dr. G. F. Smith of the Department of Chemistry, University of Illinois. Dr. Smith's report follows.

"The sample was machined into a number of blocks weighing 5 gms. For chemical analysis these were etched in dilute nitric acid, dried, and weighed. The nitric and hydrochloric acids used in the work were C.P. reagents redistilled from quartz and stored in quartz bottles. All other reagents were especially tested for the presence of the materials sought. In all cases, methods were selected that are known to be most delicate and specific, and several different methods were employed before negative results were accepted. For silicon the perchloric acid method of Willard and Cake was used. This showed less than 0.001% silicon which might well have been experimental error. Hydrogen sulphide precipitation of filtrate from silver chloride showed only silver, with gold and copper absent. The absence of copper was confirmed by testing the filtrate from silver chloride, made ammoniacal, with an alcoholic solution of haematoxylin. This test has a delicacy of one part in a million.

In the same way iron, aluminum, nickel, zinc and manganese were tested for in the filtrate from silver chloride precipitation. The test for manganese was checked by the colorimetric periodate method of Willard and Greathouse. This test also is delicate to one part in a million. The conclusion is that the total impurities contained in the silver amount to less than one one-hundredth of one per cent."

IV. DETERMINATION OF CAPILLARY CONSTANT OF SILVER

9. *Capillary Constant of Silver.*—Table 2 gives the actual film measurements. These measurements are corrected for distortion and

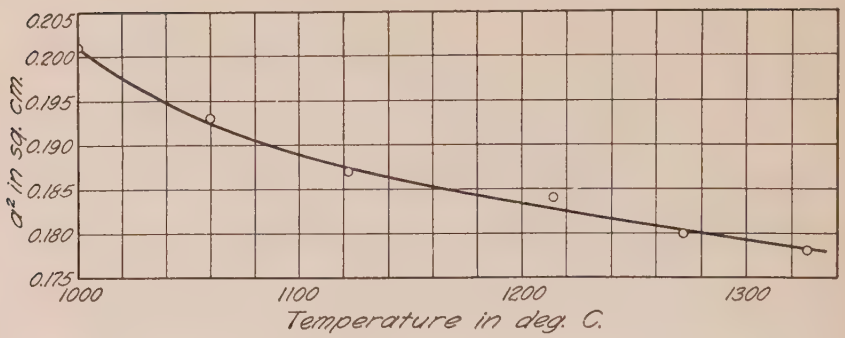

Fig. 6. Variation of Capillary Constant of Silver with Temperature

film shrinkage as explained on page 40 and Tables 7 and 8 of Bulletin 173, and the corrected values are given in Table 3. The values of a^2 determined from these data are given in Table 4. The method of calculation is shown minutely in Tables 10 and 11 of Bulletin 173, and so need not be described in detail in this report.

The capillary constant of silver plotted against the temperature is shown in Fig. 6.

TABLE 2

FILM MEASUREMENTS USED IN CALCULATION OF CAPILLARY CONSTANT OF SILVER

Film No.	Temp. deg. C.	h cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	H cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	$2r$ cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$
2	1000				0.623	0.002		0.581	0.001	
					0.627	0.002		0.583	0.001	
					0.623	0.002		0.587	0.005	
					0.625	0.000		0.582	0.000	
					0.627	0.002		0.579	0.003	
					0.625	0.000		0.585	0.003	
					0.627	0.002		0.580	0.002	
					0.623	0.002		0.582	0.000	
					0.628	0.003		0.582	0.000	
					0.625	0.000		0.581	0.001	
	Av.				0.625		0.000276	0.582		0.000499
3	1000	0.352	0.006		0.622	0.001		0.585	0.000	
		0.360	0.002		0.622	0.001		0.583	0.002	
		0.358	0.000		0.620	0.001		0.584	0.001	
		0.355	0.003		0.618	0.003		0.584	0.001	
		0.363	0.005		0.621	0.000		0.586	0.001	
		0.357	0.001		0.622	0.001		0.585	0.000	
		0.360	0.002		0.627	0.006		0.585	0.000	
		0.357	0.003		0.622	0.001		0.585	0.000	
		0.357	0.003		0.618	0.003		0.585	0.000	
		0.357	0.003		0.620	0.001		0.584	0.001	
	Av.	0.358		0.00074	0.621		0.000551	0.585		0.000202
4	1000	0.355	0.000		0.620	0.002		0.584	0.001	
		0.356	0.001		0.620	0.002		0.584	0.001	
		0.357	0.002		0.625	0.003		0.582	0.001	
		0.352	0.003		0.623	0.001		0.582	0.001	
		0.358	0.003		0.620	0.002		0.584	0.001	
		0.355	0.000		0.622	0.000		0.584	0.001	
		0.356	0.001		0.625	0.003		0.583	0.000	
		0.355	0.000		0.623	0.001		0.582	0.001	
		0.355	0.000		0.620	0.002		0.580	0.003	
		0.355	0.000		0.624	0.002		0.583	0.000	
	Av.	0.355		0.000344	0.622		0.000425	0.583		0.000283
5	1000	0.355	0.002		0.625	0.002		0.583	0.000	
		0.354	0.003		0.628	0.001		0.583	0.000	
		0.357	0.000		0.626	0.001		0.583	0.000	
		0.355	0.002		0.627	0.000		0.583	0.000	
		0.357	0.000		0.628	0.001		0.585	0.002	
		0.355	0.002		0.628	0.001		0.583	0.000	
		0.357	0.000		0.627	0.000		0.581	0.002	
		0.358	0.001		0.629	0.002		0.583	0.000	
		0.362	0.005		0.625	0.002		0.582	0.001	
		0.358	0.001		0.625	0.002		0.585	0.002	
	Av.	0.357		0.000492	0.627		0.000317	0.583		0.00025
6	1000	0.352	0.002		0.622	0.006		0.582	0.002	
		0.351	0.003		0.628	0.000		0.583	0.001	
		0.358	0.004		0.630	0.002		0.581	0.003	
		0.357	0.003		0.630	0.002		0.585	0.001	
		0.350	0.004		0.630	0.002		0.585	0.001	
		0.350	0.004		0.625	0.003		0.584	0.000	
		0.350	0.004		0.630	0.002		0.580	0.004	
		0.358	0.004		0.630	0.002		0.585	0.001	
		0.355	0.001		0.628	0.000		0.585	0.001	
		0.355	0.001		0.630	0.002		0.587	0.003	
	Av.	0.354		0.00074	0.628		0.000593	0.584		0.000465

TABLE 2 (Continued)

FILM MEASUREMENTS USED IN CALCULATION OF CAPILLARY CONSTANT OF SILVER

Film No.	Temp. deg. C.	h cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	H cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	$2r$ cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$
7	1000	0.356	0.002		0.627	0.003		0.580	0.003	
		0.356	0.002		0.625	0.001		0.588	0.005	
		0.350	0.004		0.622	0.002		0.588	0.005	
		0.355	0.001		0.623	0.001		0.585	0.002	
		0.352	0.002		0.624	0.000		0.585	0.002	
		0.353	0.001		0.627	0.003		0.583	0.000	
		0.355	0.001		0.625	0.001		0.581	0.002	
		0.355	0.001		0.623	0.001		0.580	0.003	
		0.353	0.001		0.621	0.003		0.580	0.003	
		0.355	0.001		0.620	0.004		0.580	0.003	
	Av.	0.354		0.000418	0.624		0.000465	0.583		0.00074
8	1060	0.365	0.003		0.618	0.001		0.588	0.001	
		0.363	0.001		0.620	0.002		0.588	0.001	
		0.362	0.000		0.620	0.002		0.585	0.002	
		0.364	0.002		0.618	0.001		0.585	0.002	
		0.368	0.006		0.617	0.002		0.590	0.003	
		0.363	0.001		0.620	0.001		0.592	0.005	
		0.360	0.002		0.618	0.001		0.590	0.003	
		0.362	0.000		0.620	0.001		0.582	0.005	
		0.365	0.003		0.618	0.001		0.590	0.003	
		0.362	0.000		0.620	0.001		0.583	0.004	
	Av.	0.362		0.000565	0.619		0.00031	0.587		0.00074
9	1060	0.385	0.006		0.609	0.001		0.585	0.001	
		0.381	0.002		0.613	0.003		0.586	0.000	
		0.376	0.003		0.608	0.002		0.586	0.000	
		0.388	0.009		0.615	0.005		0.585	0.001	
		0.380	0.001		0.608	0.002		0.583	0.003	
		0.375	0.004		0.612	0.002		0.583	0.003	
		0.375	0.004		0.608	0.002		0.590	0.004	
		0.375	0.004		0.609	0.001		0.588	0.002	
		0.380	0.001		0.612	0.002		0.583	0.003	
		0.377	0.002		0.610	0.000		0.587	0.001	
	Av.	0.379		0.000942	0.610		0.000532	0.586		0.000505
10	1060	0.415	0.012		0.612	0.000		0.583	0.000	
		0.412	0.009		0.609	0.003		0.583	0.000	
		0.392	0.011		0.607	0.005		0.585	0.002	
		0.403	0.000		0.615	0.003		0.583	0.000	
		0.398	0.005		0.611	0.001		0.585	0.002	
		0.403	0.000		0.615	0.003		0.583	0.000	
		0.402	0.001		0.615	0.003		0.580	0.003	
		0.405	0.002		0.613	0.001		0.579	0.004	
		0.402	0.001		0.615	0.003		0.583	0.000	
		0.398	0.005		0.611	0.001		0.587	0.004	
	Av.	0.403		0.00142	0.612		0.000606	0.583		0.000498
11	1060	0.387	0.000		0.612	0.001		0.580	0.003	
		0.387	0.000		0.618	0.005		0.582	0.001	
		0.385	0.002		0.610	0.003		0.587	0.004	
		0.385	0.002		0.615	0.002		0.585	0.002	
		0.392	0.005		0.613	0.000		0.580	0.003	
		0.383	0.004		0.613	0.000		0.580	0.003	
		0.387	0.000		0.613	0.000		0.582	0.001	
		0.390	0.003		0.613	0.000		0.588	0.005	
		0.388	0.001		0.610	0.003		0.583	0.000	
		0.387	0.000		0.612	0.001		0.586	0.003	
	Av.	0.387		0.000553	0.613		0.000498	0.583		0.000613

TABLE 2 (Continued)

FILM MEASUREMENTS USED IN CALCULATION OF CAPILLARY CONSTANT OF SILVER

Film No.	Temp. deg. C.	h cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	H cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	$2r$ cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$
12	1060	0.385	0.001		0.615	0.002		0.595	0.003	
		0.380	0.004		0.617	0.000		0.592	0.000	
		0.380	0.004		0.617	0.000		0.593	0.001	
		0.384	0.000		0.615	0.002		0.588	0.004	
		0.384	0.000		0.617	0.000		0.588	0.004	
		0.383	0.001		0.615	0.002		0.591	0.001	
		0.382	0.002		0.620	0.003		0.598	0.006	
		0.385	0.001		0.618	0.001		0.590	0.002	
		0.388	0.004		0.617	0.000		0.592	0.000	
		0.385	0.001		0.618	0.001		0.593	0.001	
	Av.	0.384		0.000533	0.617		0.000344	0.592		0.000646
13	1122	0.406	0.002		0.597	0.001		0.578	0.003	
		0.410	0.002		0.595	0.001		0.583	0.002	
		0.410	0.002		0.597	0.001		0.582	0.001	
		0.406	0.002		0.595	0.001		0.581	0.000	
		0.413	0.005		0.590	0.006		0.580	0.001	
		0.410	0.002		0.595	0.001		0.577	0.004	
		0.404	0.004		0.592	0.004		0.579	0.002	
		0.405	0.003		0.597	0.001		0.583	0.002	
		0.407	0.001		0.599	0.003		0.582	0.001	
		0.405	0.003		0.602	0.006		0.583	0.002	
	Av.	0.408		0.000613	0.596		0.00074	0.581		0.000478
14	1122				0.605	0.003		0.582	0.001	
					0.600	0.002		0.583	0.000	
					0.600	0.002		0.585	0.002	
					0.602	0.000		0.586	0.003	
					0.603	0.001		0.584	0.001	
					0.602	0.000		0.582	0.001	
					0.604	0.002		0.583	0.000	
					0.600	0.002		0.583	0.000	
					0.602	0.000		0.582	0.001	
					0.597	0.005		0.583	0.000	
	Av.				0.602		0.000511	0.583		0.000296
15	1122	0.387	0.001		0.608	0.003		0.595	0.004	
		0.388	0.002		0.612	0.001		0.592	0.001	
		0.385	0.001		0.610	0.001		0.593	0.002	
		0.388	0.002		0.610	0.001		0.592	0.001	
		0.385	0.001		0.613	0.002		0.588	0.003	
		0.390	0.004		0.613	0.002		0.592	0.001	
		0.388	0.002		0.613	0.002		0.589	0.002	
		0.384	0.002		0.610	0.001		0.592	0.001	
		0.383	0.003		0.612	0.001		0.590	0.001	
		0.383	0.003		0.609	0.002		0.591	0.000	
	Av.	0.386		0.000525	0.611		0.000384	0.591		0.000438
16	1122				0.611	0.004		0.585	0.002	
					0.605	0.002		0.585	0.002	
					0.607	0.000		0.590	0.003	
					0.605	0.002		0.590	0.003	
					0.605	0.002		0.583	0.004	
					0.607	0.000		0.587	0.000	
					0.608	0.001		0.585	0.002	
					0.605	0.002		0.590	0.003	
					0.608	0.001		0.587	0.000	
					0.607	0.000		0.592	0.005	
	Av.				0.607		0.000417	0.587		0.00064

TABLE 2 (Continued)

FILM MEASUREMENTS USED IN CALCULATION OF CAPILLARY CONSTANT OF SILVER

Film No.	Temp. deg. C.	h cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	H cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	$2r$ cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$
17	1122	0.400	0.003		0.598	0.001		0.593	0.006	
		0.403	0.000		0.598	0.001		0.586	0.001	
		0.400	0.003		0.603	0.004		0.586	0.001	
		0.393	0.010		0.596	0.003		0.585	0.002	
		0.395	0.008		0.595	0.004		0.586	0.001	
		0.405	0.002		0.604	0.005		0.585	0.002	
		0.409	0.006		0.599	0.000		0.587	0.000	
		0.404	0.001		0.597	0.002		0.588	0.001	
		0.410	0.007		0.602	0.003		0.590	0.003	
		0.411	0.008		0.598	0.001		0.588	0.001	
	Av.	0.403		0.00129	0.599		0.00064	0.587		0.000539
18	1214	0.385	0.002		0.590	0.004		0.580	0.001	
		0.390	0.003		0.593	0.001		0.580	0.001	
		0.387	0.000		0.597	0.003		0.583	0.002	
		0.388	0.001		0.591	0.003		0.581	0.000	
		0.388	0.001		0.597	0.003		0.583	0.002	
		0.387	0.000		0.595	0.001		0.583	0.002	
		0.385	0.002		0.593	0.001		0.580	0.001	
		0.383	0.004		0.595	0.001		0.578	0.003	
		0.385	0.002		0.595	0.001		0.579	0.002	
		0.388	0.001		0.597	0.003		0.581	0.000	
	Av.	0.387		0.000445	0.594		0.000532	0.581		0.000377
19	1214	0.392	0.003		0.598	0.001		0.570	0.006	
		0.392	0.003		0.595	0.002		0.572	0.004	
		0.398	0.003		0.598	0.001		0.577	0.001	
		0.397	0.002		0.597	0.000		0.575	0.001	
		0.404	0.005		0.600	0.003		0.580	0.004	
		0.392	0.003		0.597	0.000		0.575	0.001	
		0.390	0.005		0.598	0.001		0.578	0.002	
		0.392	0.003		0.595	0.002		0.575	0.001	
		0.388	0.007		0.595	0.002		0.575	0.001	
		0.393	0.002		0.597	0.000		0.578	0.002	
	Av.	0.395		0.000876	0.597		0.00035	0.576		0.00064
20	1214	0.405	0.004		0.594	0.003		0.588	0.000	
		0.395	0.004		0.594	0.003		0.585	0.003	
		0.392	0.009		0.591	0.000		0.590	0.002	
		0.395	0.006		0.592	0.001		0.588	0.000	
		0.407	0.006		0.590	0.001		0.590	0.002	
		0.400	0.001		0.592	0.001		0.588	0.000	
		0.412	0.011		0.590	0.001		0.590	0.002	
		0.402	0.001		0.590	0.001		0.590	0.002	
		0.401	0.000		0.588	0.003		0.587	0.001	
		0.403	0.002		0.590	0.001		0.587	0.001	
	Av.	0.401		0.00126	0.591		0.00039	0.588		0.00037
21	1214	0.387	0.002		0.599	0.000		0.587	0.001	
		0.387	0.002		0.598	0.001		0.587	0.001	
		0.384	0.001		0.595	0.004		0.586	0.000	
		0.387	0.002		0.597	0.002		0.586	0.000	
		0.387	0.002		0.603	0.004		0.587	0.001	
		0.382	0.003		0.599	0.000		0.583	0.003	
		0.380	0.005		0.602	0.003		0.580	0.006	
		0.390	0.005		0.602	0.003		0.585	0.001	
		0.382	0.003		0.597	0.002		0.584	0.002	
		0.383	0.002		0.599	0.000		0.590	0.004	
	Av.	0.385		0.000675	0.599		0.000538	0.586		0.000593

TABLE 2 (Continued)

FILM MEASUREMENTS USED IN CALCULATION OF CAPILLARY CONSTANT OF SILVER

Film No.	Temp. deg. C.	h cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	H cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	$2r$ cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$
22	1214	0.393	0.002		0.602	0.005		0.580	0.001	
		0.391	0.000		0.597	0.000		0.580	0.001	
		0.392	0.001		0.597	0.000		0.579	0.002	
		0.392	0.001		0.596	0.001		0.580	0.001	
		0.388	0.003		0.598	0.001		0.579	0.002	
		0.395	0.004		0.596	0.001		0.580	0.001	
		0.390	0.001		0.596	0.001		0.583	0.002	
		0.392	0.001		0.595	0.002		0.582	0.001	
		0.386	0.005		0.597	0.000		0.581	0.000	
		0.388	0.003		0.599	0.002		0.582	0.001	
	Av.	0.391		0.00058	0.597		0.00043	0.581		0.000303
23	1272	0.393	0.003		0.580	0.001		0.580	0.002	
		0.398	0.002		0.580	0.001		0.583	0.001	
		0.389	0.003		0.582	0.001		0.582	0.000	
		0.395	0.001		0.582	0.001		0.580	0.002	
		0.395	0.001		0.582	0.001		0.583	0.001	
		0.397	0.001		0.580	0.001		0.583	0.001	
		0.398	0.002		0.580	0.001		0.585	0.003	
		0.398	0.002		0.579	0.002		0.583	0.001	
		0.400	0.004		0.580	0.001		0.582	0.000	
		0.395	0.001		0.582	0.001		0.578	0.004	
	Av.	0.396		0.000505	0.581		0.000249	0.582		0.000432
24	1272	0.391	0.006		0.582	0.001		0.580	0.001	
		0.383	0.002		0.581	0.000		0.577	0.004	
		0.380	0.005		0.581	0.000		0.578	0.003	
		0.382	0.003		0.583	0.002		0.580	0.001	
		0.388	0.003		0.579	0.002		0.581	0.000	
		0.383	0.002		0.578	0.003		0.581	0.000	
		0.380	0.005		0.582	0.001		0.582	0.001	
		0.386	0.001		0.580	0.001		0.583	0.002	
		0.387	0.002		0.580	0.001		0.580	0.001	
		0.385	0.000		0.580	0.001		0.588	0.007	
	Av.	0.385		0.00077	0.581		0.00033	0.581		0.00064
25	1272	0.385	0.001		0.575	0.003		0.581	0.002	
		0.381	0.005		0.575	0.003		0.585	0.002	
		0.383	0.003		0.577	0.001		0.585	0.002	
		0.385	0.001		0.577	0.001		0.587	0.004	
		0.388	0.002		0.580	0.002		0.582	0.001	
		0.390	0.004		0.580	0.002		0.582	0.001	
		0.387	0.001		0.580	0.002		0.580	0.003	
		0.385	0.001		0.580	0.002		0.582	0.001	
		0.385	0.001		0.578	0.000		0.582	0.001	
		0.387	0.001		0.577	0.001		0.581	0.002	
	Av.	0.386		0.000553	0.578		0.000432	0.583		0.000478
26	1272	0.390	0.002		0.575	0.002		0.588	0.001	
		0.392	0.000		0.577	0.000		0.587	0.002	
		0.390	0.002		0.577	0.000		0.590	0.001	
		0.391	0.001		0.578	0.001		0.590	0.001	
		0.393	0.001		0.578	0.001		0.583	0.006	
		0.390	0.002		0.576	0.001		0.592	0.003	
		0.395	0.003		0.580	0.003		0.590	0.001	
		0.393	0.001		0.583	0.006		0.590	0.001	
		0.393	0.001		0.575	0.002		0.590	0.001	
		0.391	0.001		0.575	0.002		0.590	0.001	
	Av.	0.392		0.00037	0.577		0.000552	0.589		0.000532

TABLE 2 (Continued)

FILM MEASUREMENTS USED IN CALCULATION OF CAPILLARY CONSTANT OF SILVER

Film No.	Temp. deg. C.	h cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	H cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	$2r$ cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$
27	1272	0.385	0.002		0.583	0.002		0.576	0.005	
		0.385	0.002		0.580	0.000		0.577	0.004	
		0.385	0.002		0.577	0.004		0.582	0.001	
		0.383	0.004		0.580	0.000		0.582	0.001	
		0.385	0.002		0.580	0.000		0.582	0.001	
		0.390	0.003		0.582	0.001		0.580	0.001	
		0.390	0.003		0.582	0.001		0.582	0.001	
		0.388	0.001		0.580	0.000		0.582	0.001	
		0.390	0.003		0.580	0.001		0.580	0.001	
		0.385	0.002		0.582	0.001		0.582	0.001	
	Av.	0.387		0.000565	0.581		0.000344	0.581		0.000498
28	1327	0.390	0.001		0.565	0.007		0.588	0.001	
		0.388	0.001		0.574	0.002		0.590	0.003	
		0.392	0.003		0.570	0.002		0.586	0.001	
		0.393	0.004		0.575	0.003		0.587	0.000	
		0.386	0.003		0.571	0.001		0.588	0.001	
		0.388	0.001		0.575	0.003		0.585	0.002	
		0.388	0.001		0.573	0.001		0.585	0.002	
		0.388	0.001		0.572	0.000		0.590	0.003	
		0.390	0.001		0.573	0.001		0.586	0.001	
		0.388	0.001		0.571	0.001		0.588	0.001	
	Av.	0.389		0.000404	0.572		0.000633	0.587		0.000398
29	1327	0.382	0.006		0.577	0.006		0.588	0.002	
		0.385	0.003		0.575	0.004		0.588	0.002	
		0.389	0.001		0.570	0.001		0.588	0.002	
		0.385	0.003		0.572	0.001		0.590	0.004	
		0.390	0.002		0.568	0.003		0.588	0.002	
		0.395	0.007		0.570	0.001		0.589	0.003	
		0.393	0.005		0.570	0.001		0.582	0.004	
		0.397	0.009		0.568	0.003		0.582	0.004	
		0.380	0.008		0.572	0.001		0.582	0.004	
		0.388	0.000		0.568	0.003		0.582	0.004	
	Av.	0.388		0.00106	0.571		0.000612	0.586		0.00074
30	1327	0.393	0.002		0.571	0.002		0.585	0.000	
		0.393	0.002		0.573	0.000		0.585	0.000	
		0.389	0.002		0.573	0.000		0.584	0.001	
		0.390	0.001		0.572	0.001		0.586	0.001	
		0.395	0.004		0.573	0.000		0.585	0.000	
		0.394	0.003		0.574	0.001		0.585	0.000	
		0.387	0.004		0.570	0.003		0.585	0.000	
		0.388	0.003		0.576	0.003		0.585	0.000	
		0.389	0.002		0.574	0.001		0.585	0.000	
		0.390	0.001		0.572	0.001		0.587	0.002	
	Av.	0.391		0.000586	0.573		0.000303	0.585		0.000182
31	1327	0.387	0.003		0.567	0.000		0.587	0.004	
		0.380	0.004		0.558	0.009		0.583	0.000	
		0.385	0.001		0.566	0.001		0.580	0.003	
		0.382	0.002		0.563	0.004		0.582	0.001	
		0.382	0.002		0.565	0.002		0.585	0.002	
		0.382	0.002		0.569	0.002		0.583	0.000	
		0.385	0.001		0.567	0.000		0.580	0.003	
		0.385	0.001		0.565	0.002		0.581	0.002	
		0.389	0.005		0.567	0.000		0.584	0.001	
		0.382	0.002		0.569	0.002		0.580	0.003	
	Av.	0.384		0.000593	0.567		0.000769	0.583		0.000478

TABLE 2 (Concluded)

FILM MEASUREMENTS USED IN CALCULATION OF CAPILLARY CONSTANT OF SILVER

Film No.	Temp. deg. C.	h cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	H cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$	$2r$ cm.	v Deviation from mean	Probable error $0.6745\sqrt{\frac{v^2}{n(n-1)}}$
32	1327	0.390	0.002		0.575	0.001		0.583	0.002	
		0.384	0.004		0.577	0.003		0.582	0.001	
		0.385	0.003		0.572	0.002		0.578	0.007	
		0.388	0.000		0.572	0.002		0.584	0.003	
		0.388	0.000		0.571	0.003		0.583	0.002	
		0.387	0.001		0.573	0.001		0.583	0.002	
		0.388	0.000		0.572	0.002		0.583	0.002	
		0.387	0.001		0.571	0.003		0.582	0.001	
		0.392	0.004		0.577	0.003		0.582	0.001	
		0.392	0.004		0.576	0.002		0.581	0.000	
	Av.	0.388		0.000566	0.574		0.000525	0.581		0.000626

TABLE 3

FILM MEASUREMENTS CORRECTED FOR DISTORTION AND SHRINKAGE

Film No.	h cm.	Corrected h cm.	H cm.	Corrected H cm.	$2r$ cm.	Corrected $2r$ cm.	Corrected r cm.
2			0.625	0.5956	0.582	0.5546	0.2773
3	0.358	0.3411	0.621	0.5918	0.585	0.5575	0.2788
4	0.355	0.3383	0.622	0.5927	0.583	0.5556	0.2778
5	0.357	0.3402	0.627	0.5975	0.583	0.5556	0.2778
6	0.354	0.3373	0.628	0.5985	0.584	0.5566	0.2783
7	0.354	0.3373	0.624	0.5947	0.583	0.5556	0.2778
8	0.362	0.3449	0.619	0.5899	0.587	0.5594	0.2797
9	0.379	0.3611	0.610	0.5813	0.586	0.5585	0.2793
10	0.403	0.3841	0.612	0.5832	0.583	0.5556	0.2778
11	0.387	0.3688	0.613	0.5842	0.583	0.5556	0.2778
12	0.384	0.3660	0.617	0.5880	0.592	0.5642	0.2821
13	0.408	0.3888	0.596	0.5680	0.581	0.5537	0.2769
14			0.602	0.5737	0.583	0.5556	0.2778
15	0.386	0.3679	0.611	0.5823	0.591	0.5632	0.2816
16			0.607	0.5785	0.587	0.5594	0.2797
17	0.403	0.3841	0.599	0.5708	0.587	0.5594	0.2797
18	0.387	0.3688	0.594	0.5661	0.581	0.5537	0.2769
19	0.395	0.3764	0.597	0.5689	0.576	0.5489	0.2745
20	0.401	0.3822	0.591	0.5632	0.588	0.5604	0.2802
21	0.385	0.3669	0.599	0.5708	0.586	0.5585	0.2793
22	0.391	0.3726	0.597	0.5689	0.581	0.5537	0.2769
23	0.396	0.3774	0.581	0.5537	0.582	0.5546	0.2773
24	0.385	0.3669	0.581	0.5537	0.581	0.5537	0.2769
25	0.386	0.3679	0.578	0.5508	0.583	0.5556	0.2778
26	0.392	0.3736	0.577	0.5499	0.589	0.5613	0.2807
27	0.387	0.3688	0.581	0.5537	0.581	0.5537	0.2769
28	0.389	0.3707	0.572	0.5451	0.587	0.5594	0.2797
29	0.388	0.3698	0.571	0.5442	0.586	0.5585	0.2793
30	0.391	0.3726	0.573	0.5461	0.585	0.5575	0.2788
31	0.384	0.3659	0.567	0.5404	0.583	0.5556	0.2778
32	0.388	0.3698	0.574	0.5470	0.581	0.5537	0.2769

TABLE 4

CAPILLARY CONSTANT OF SILVER

$a^2 = 2T/g\rho$

Temp. deg. C.	Film No.	a^2 cm.^{2}	Mean Value of a^2 cm.^{2}
1000	2	0.2001	0.201 ± 0.0007
	3	0.1993	
	4	0.2001	
	5	0.2005	
	6	0.2028	
	7	0.2011	
1060	8	0.1985	0.193 ± 0.0007
	9	0.1915	
	10	0.1885	
	11	0.1902	
	12	0.1953	
1122	13	0.1828	0.187 ± 0.0007
	14	0.1856	
	15	0.1931	
	16	0.1889	
	17	0.1868	
1214	18	0.1835	0.184 ± 0.0007
	19	0.1828	
	20	0.1840	
	21	0.1865	
	22	0.1841	
1272	23	0.1793	0.180 ± 0.0007
	24	0.1803	
	25	0.1792	
	26	0.1811	
	27	0.1798	
1327	28	0.1792	0.178 ± 0.0007
	29	0.1786	
	30	0.1786	
	31	0.1765	
	32	0.1779	

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